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Kano

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(54) **PIEZOELECTRIC SPEAKER**

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(73) Assignee: **Panasonic Intellectual Property Management Co., Ltd.**, Osaka (JP)

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H04R 17/00 (2006.01)

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CPC ***H04R 17/00*** (2013.01)

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USPC 381/190, 152, 191; 310/317, 322, 324, 310/340, 348, 358
See application file for complete search history.

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(57) **ABSTRACT**

A piezoelectric speaker includes: a diaphragm which includes a substrate and a plurality of piezoelectric elements arranged on the substrate; and a frame for supporting the substrate at an outer peripheral portion thereof. The plural piezoelectric elements include first piezoelectric elements each having a first number of layers, and second piezoelectric elements each having a second number of layers, the first number of layers being larger than the second number of layers. Moreover, the second piezoelectric elements may be arranged farther from the center of the substrate than the first piezoelectric elements.

17 Claims, 8 Drawing Sheets

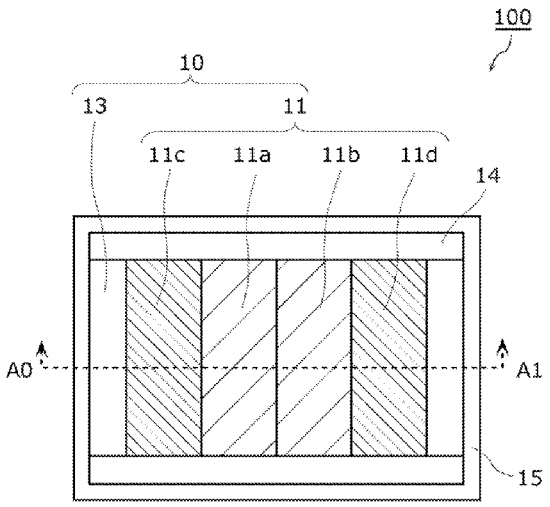

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FIG. 1

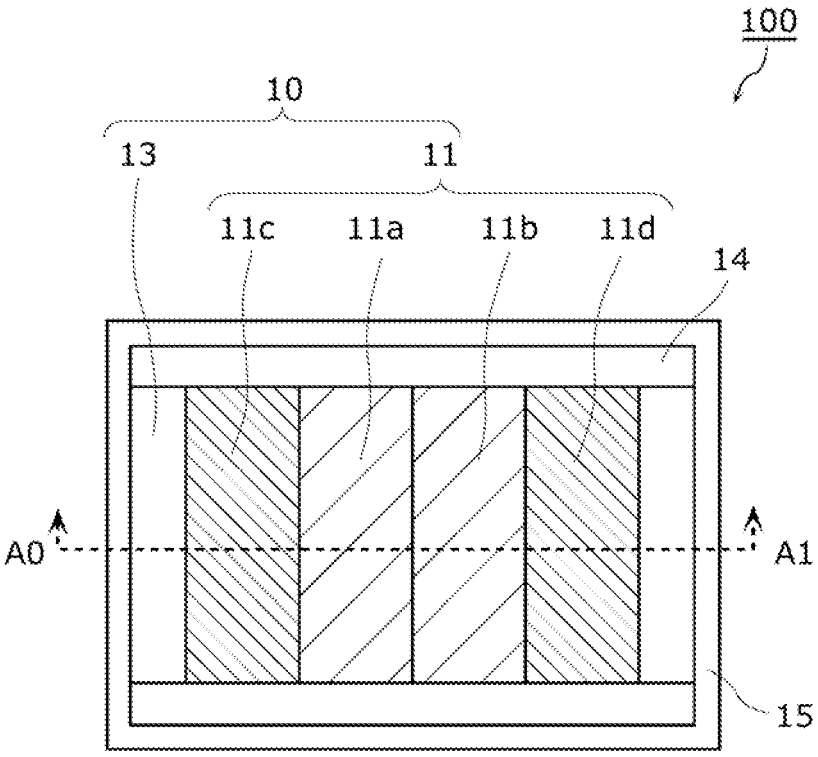

100
10
13
11
11c
11a
11b
11d
14
A0
A1
15

FIG. 2

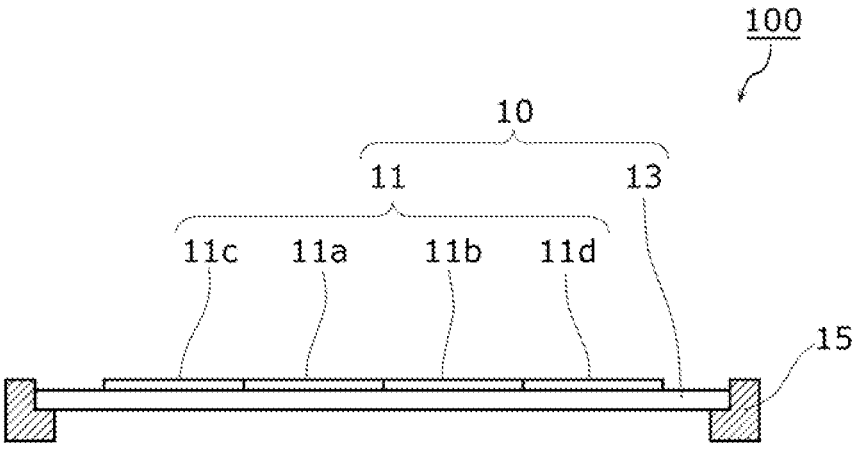

100
10
11
13
11c
11a
11b
11d
15

FIG. 3A

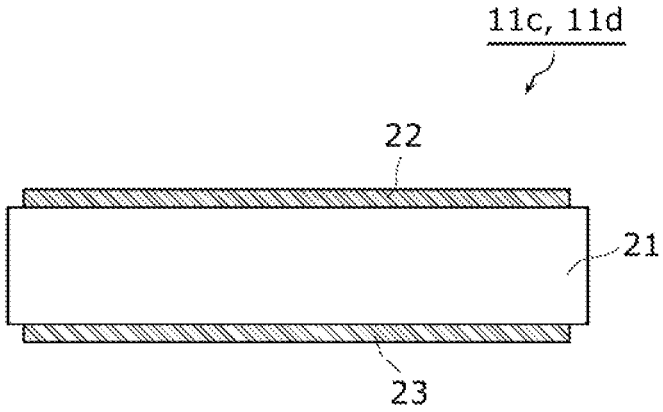


FIG. 3B

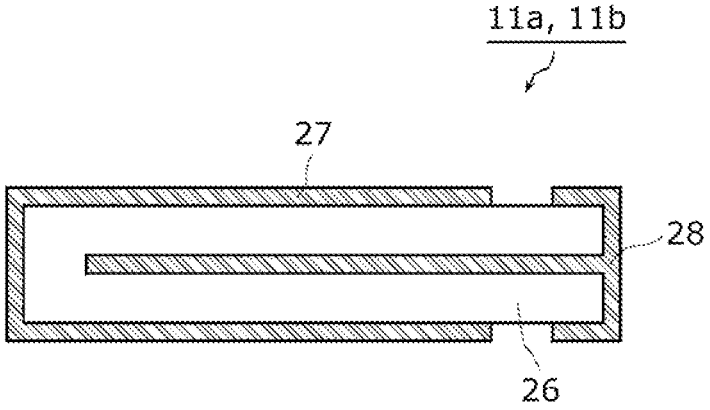


FIG. 3C

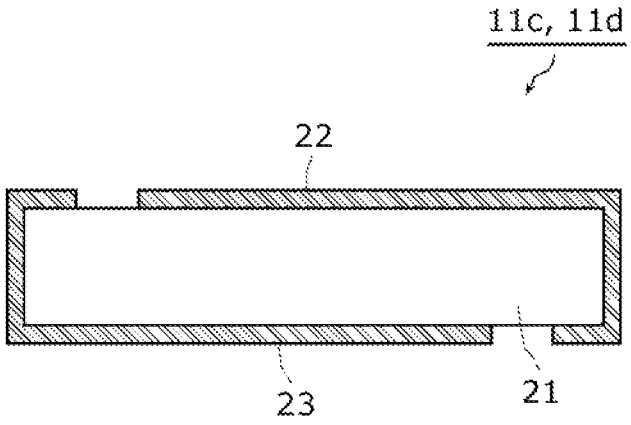

11c, 11d
22
23
21

FIG. 4A

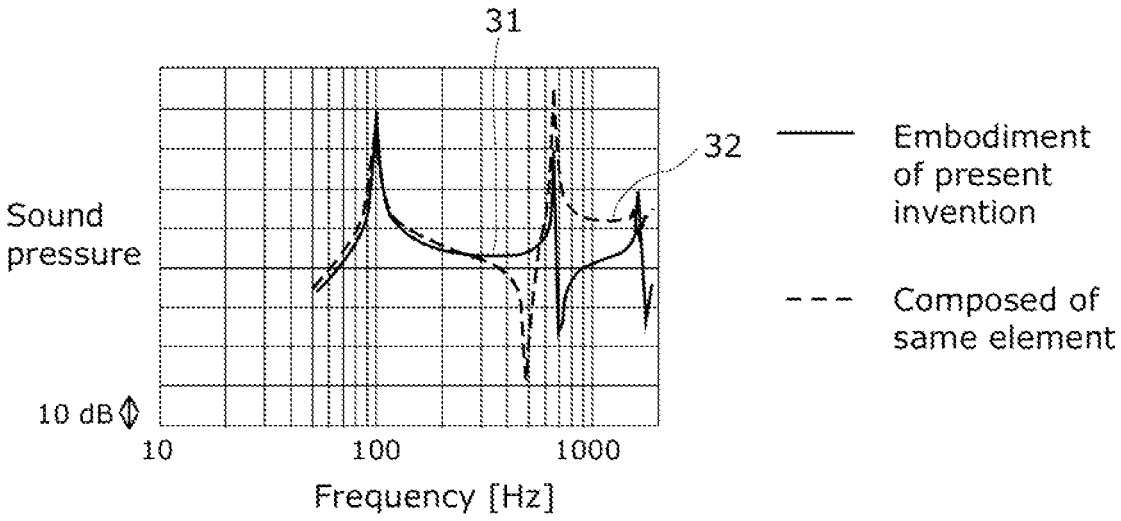

31
32
Sound pressure
10 dB
10
100
1000
Frequency [Hz]
Embodiment of present invention
Composed of same element

FIG. 4B

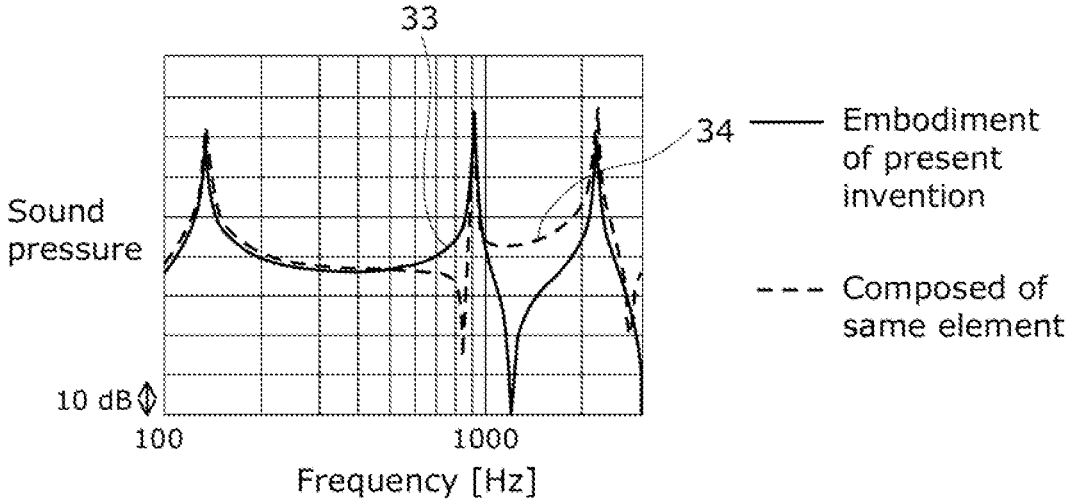

33
34
Embodiment of present invention
Composed of same element
Sound pressure
10 dB
100
1000
Frequency [Hz]

FIG. 5

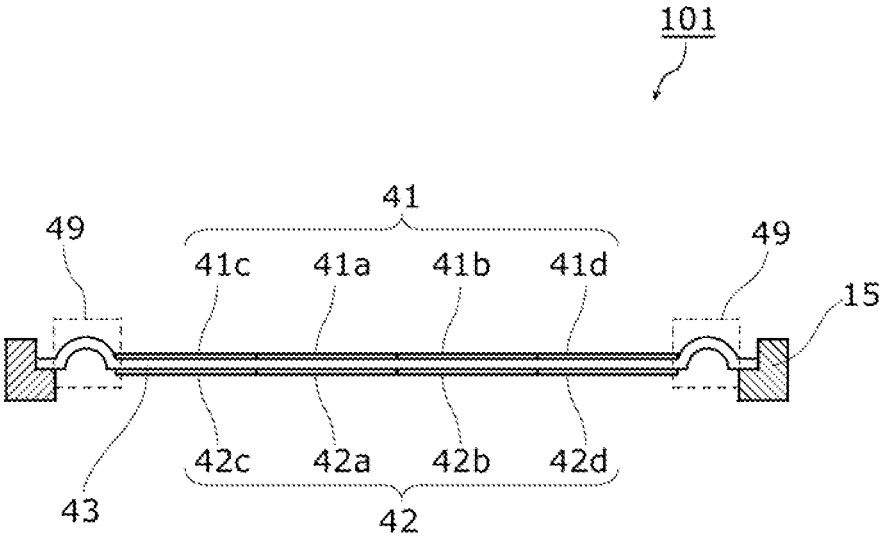

101
41
49
41c
41a
41b
41d
49
15
42c
42a
42b
42d
43
42

FIG. 6

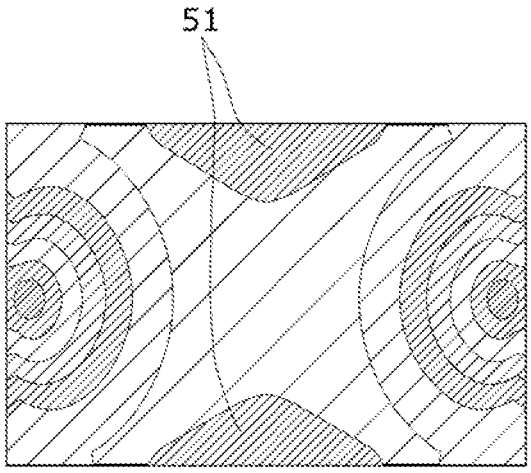


FIG. 7A

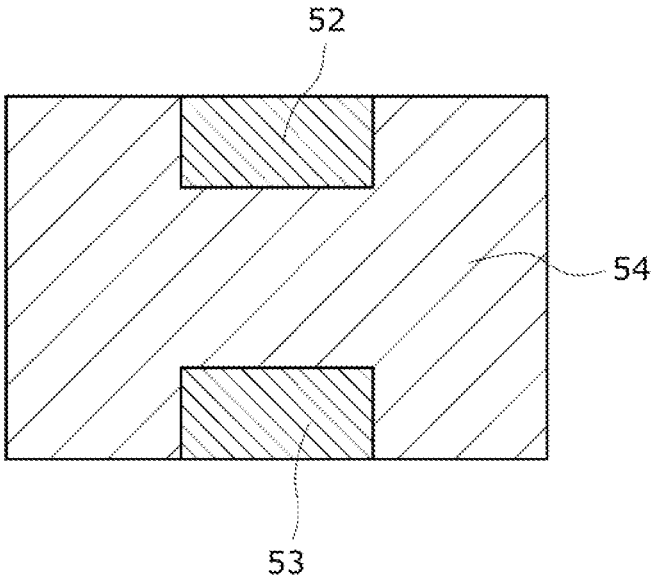


FIG. 7B

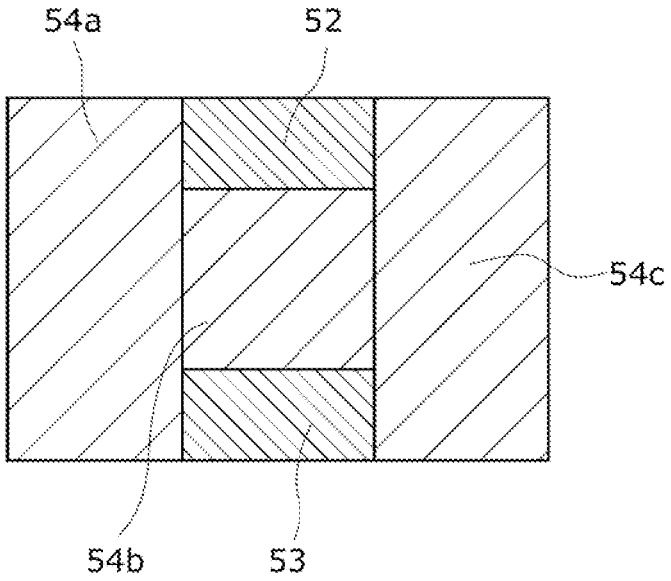


FIG. 8

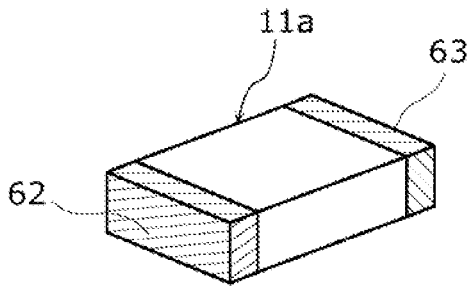


FIG. 9

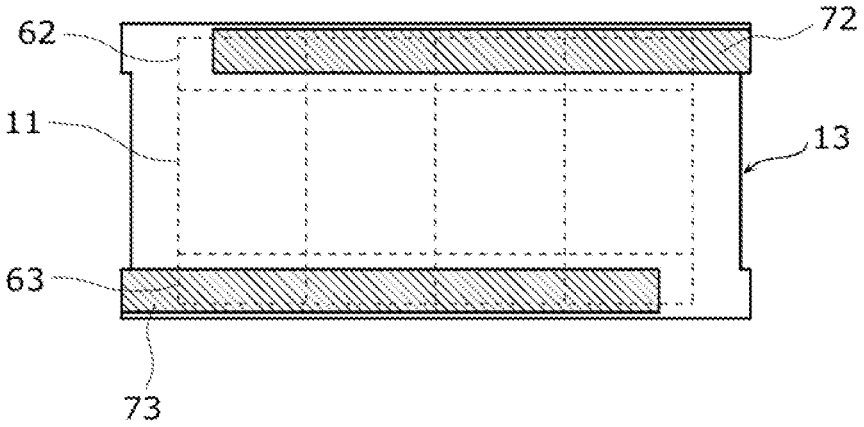


FIG. 10

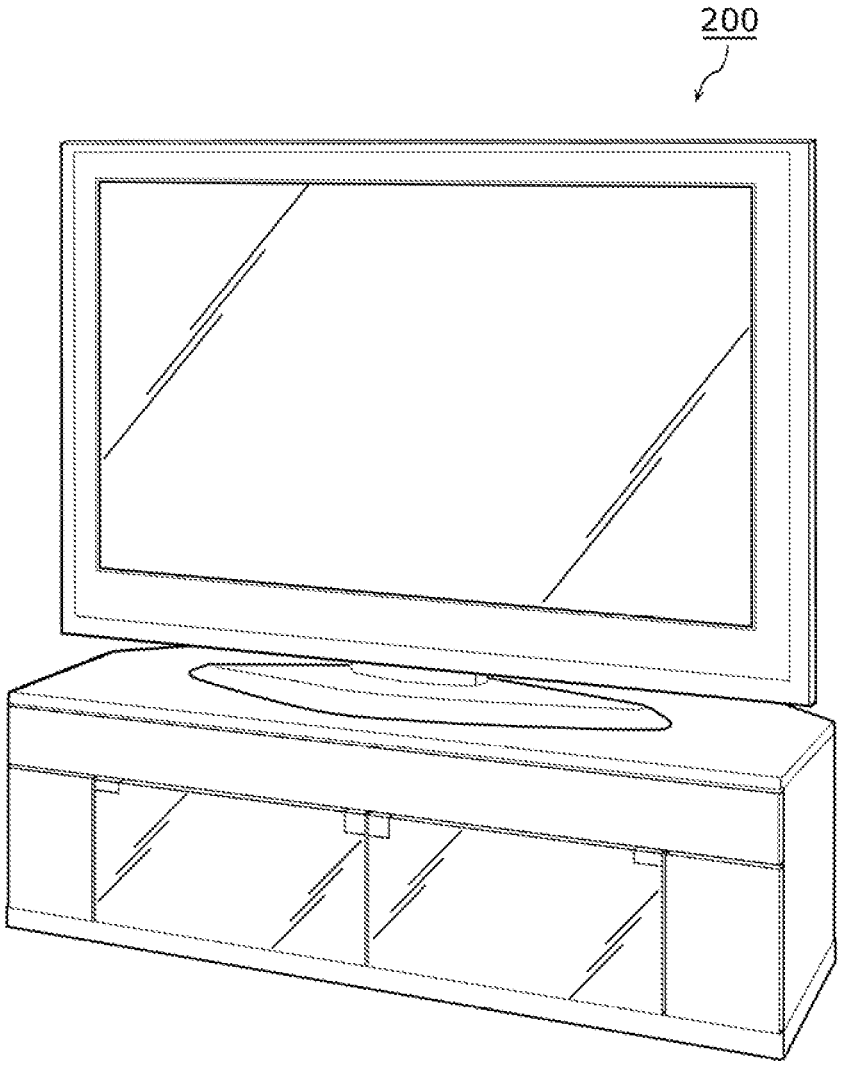


FIG. 11

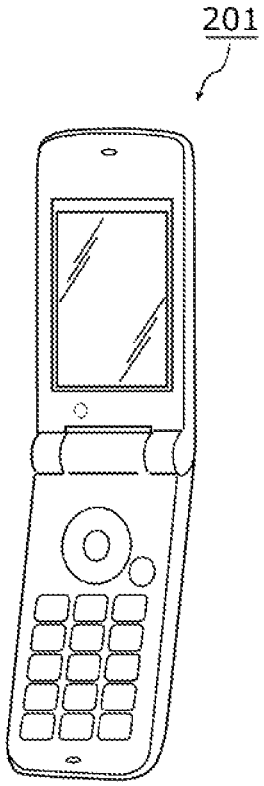
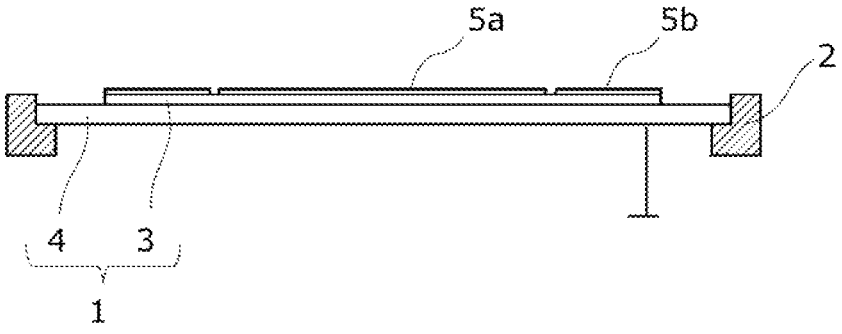


FIG. 12



PIEZOELECTRIC SPEAKER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to piezoelectric speakers using piezoelectric elements.

2. Description of the Related Art

Conventionally, there are piezoelectric speakers in each of which an electrode of a piezoelectric ceramics plate is divided so as to planarize peaks and dips of sound pressure frequency characteristics caused by resonance (for example, see Japanese Unexamined Patent Application Publication No. 5-122793). FIG. **12** is a diagram showing a conventional piezoelectric speaker disclosed in JP 5-122793.

In FIG. **12**, the conventional piezoelectric speaker is equipped with a piezoelectric sounding body **1** and a frame **2** for supporting an outer peripheral portion of the piezoelectric sounding body **1**. The piezoelectric sounding body **1** includes a round piezoelectric ceramics plate **3** and a metal plate **4** joined to the piezoelectric ceramics plate **3**. Moreover, electrodes formed on both faces of the piezoelectric ceramics plate **3** are divided at a location determined by a high-order resonance mode. Then, a voltage lower than a voltage applied to an inside electrode **5***a* is applied to an outside electrode **5***b* located outside the position where the electrodes are divided. A technique disclosed in JP 5-122793 controls a resonance mode generated in the piezoelectric sounding body **1** by variation in the applied voltage in this way. With this, the technique disclosed in JP 5-122793 improves the peaks and dips of the sound pressure frequency characteristics.

SUMMARY OF THE INVENTION

1. Technical Problem

However, with the above mentioned conventional structure, peaks and dips are relatively reduced but stress cannot be reduced because the piezoelectric ceramics plate itself is not divided. With this, stress having a value equal to or more than a certain value is generated, which breaks the piezoelectric ceramics plate. Therefore, the conventional structure has a problem that it is difficult to reproduce with large amplitude, in other words, high sound pressure. Moreover, because, in the conventional structure, signals having different voltages or different phases need to be inputted into an outside electrode and an inside electrode, a damping device needs to be additionally provided on a lead wire to the outside electrode. With this, the conventional structure has a problem of increased costs.

The present invention has been devised in view of the above-mentioned problems and has an object to provide a piezoelectric speaker capable of improving sound characteristics and reducing costs.

2. Solution to the Problem

In order to solve the conventional problem, a piezoelectric speaker according to an aspect of the present invention includes a diaphragm including a substrate and a plurality of piezoelectric elements placed on the substrate, a frame supporting the substrate at an outer peripheral portion of the substrate, wherein the piezoelectric elements include a first piezoelectric element and a second piezoelectric element having a smaller number of layers than the number of layers of the first piezoelectric element.

With this structure, the piezoelectric speaker according to an aspect of the present invention can improve reliability because use of plural piezoelectric elements enables a decrease in stress at a time of large amplitude. Moreover, the piezoelectric speaker can reproduce sound with high sound pressure by using a piezoelectric element having a layered structure. Furthermore, the piezoelectric speaker can reduce costs while reducing deterioration in sound characteristics by appropriately placing piezoelectric elements each having a different number of layers. Moreover, the piezoelectric speaker according to an aspect of the present invention can realize an improvement of sound characteristics, such as a decrease in peaks and dips or an improvement of reliability, by appropriately placing piezoelectric elements each having a different number of layers.

Moreover, the second piezoelectric element is placed farther from the center of the substrate than the first piezoelectric element.

With this structure, the piezoelectric speaker according to an aspect of the present invention can reduce costs while reducing deterioration in sound characteristics by using piezoelectric elements each having a single layer or a relatively small number of layers on a portion having a low contribution ratio to vibration.

Moreover, the second piezoelectric element is placed on the substrate, in a portion having a larger stress than a stress at a portion on which the first piezoelectric element is placed, the stress being caused by bending vibration of the substrate.

With this structure, the piezoelectric speaker according to an aspect of the present invention can enhance a maximum input level of the piezoelectric speaker because the piezoelectric speaker can decrease amplitude in a stress-concentrated portion. Therefore, the reliability of the piezoelectric speaker can be enhanced.

Moreover, each of the piezoelectric elements includes a first electrode and a second electrode through each of which an electrical signal is applied to the piezoelectric element, and each of the piezoelectric elements has a face on which both the first electrode and the second electrode are exposed.

With this structure, the piezoelectric speaker according to an aspect of the present invention can make it easier to take out a wire lead.

Moreover, the substrate includes a third electrode and a fourth electrode which are formed by printing on a face on which the piezoelectric elements are placed, the piezoelectric elements are placed such that the face on which both the first electrode and the second electrode are exposed is in contact with the face of the substrate on which the third electrode and the fourth electrode are formed, the third electrode is connected to the first electrode included in each of the piezoelectric elements, and the fourth electrode is connected to the second electrode included in each of the piezoelectric elements.

With this structure, the piezoelectric speaker according to an aspect of the present invention can realize a leadless structure.

Moreover, the substrate is made of polyethylene terephthalate.

With this structure, the piezoelectric speaker according to an aspect of the present invention can reduce the mass of vibration of the system relative to a conventional metal diaphragm, thus making it possible for sound pressure to be enhanced.

Moreover, the substrate can be made of paper.

With this structure, the piezoelectric speaker according to an aspect of the present invention can increase internal loss of the diaphragm and therefore can reduce a quality factor Q of

resonance. With this, the piezoelectric speaker can improve flatness of sound pressure characteristics.

Moreover, the substrate can be made of foam.

With this structure, the piezoelectric speaker according to an aspect of the present invention can increase internal loss of the diaphragm and therefore reduce a quality factor Q of resonance. This enables the piezoelectric speaker to enhance flatness of sound pressure characteristics.

Moreover, an edge portion is provided between the outer peripheral portion of the substrate and the frame and functions as a suspension.

With this structure, the piezoelectric speaker according to an aspect of the present invention can provide an edge regardless of a thickness of the diaphragm, making it easier to design the lowest resonance frequency.

Moreover, the edge portion has a rolled shape.

With this structure, the piezoelectric speaker according to an aspect of the present invention can reduce distortion at a time of reproduction because linearity of a support system is improved.

It is noted that the present invention can be realized not only as a piezoelectric speaker but also as audio output equipment, such as a television receiver or a mobile phone device, including this piezoelectric speaker.

3. Advantageous Effects of the Invention

The present invention can provide a piezoelectric speaker capable of realizing an improvement of sound characteristics or a decrease in costs.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view of a piezoelectric speaker according to Embodiment 1 of the present invention.

FIG. **2** is a cross-sectional view of the piezoelectric speaker according to Embodiment 1 of the present invention.

FIG. **3**A is a cross-sectional view of a single-layer piezoelectric element according to Embodiment 1 of the present invention.

FIG. **3**B is a cross-sectional view of a multilayer piezoelectric element according to Embodiment 1 of the present invention.

FIG. **3**C is a cross-sectional view of the single-layer piezoelectric element according to Embodiment 1 of the present invention.

FIG. **4**A is a graph showing sound pressure frequency characteristics of the piezoelectric speaker having a monomorph structure according to Embodiment 1 of the present invention.

FIG. **4**B is a graph showing sound pressure frequency characteristics of the piezoelectric speaker having a bimorph structure according to Embodiment 1 of the present invention.

FIG. **5** is a cross-sectional view of the piezoelectric speaker in the case where a rolled edge is used according to Embodiment 1 of the present invention.

FIG. **6** is a diagram showing a distribution of stress in a piezoelectric element according to Embodiment 2 of the present invention.

FIG. **7**A is a diagram showing configurations and locations of piezoelectric elements according to Embodiment 2 of the present invention.

FIG. **7**B is a diagram showing an example of variations in configurations and locations of the piezoelectric elements according to Embodiment 2 of the present invention.

FIG. **8** is a perspective view of a piezoelectric element according to Embodiment 3 of the present invention.

FIG. **9** is a top view of a substrate according to Embodiment 3 of the present invention.

FIG. **10** is a diagram showing a television receiver according to the embodiments of the present invention.

FIG. **11** is a diagram showing a mobile phone device according to the embodiments of the present invention.

FIG. **12** is a cross-sectional view of a conventional piezoelectric speaker.

DETAILED DESCRIPTION OF THE INVENTION

Hereafter, embodiments of the present invention will be described with reference to drawings.

Embodiment 1

A piezoelectric speaker according to Embodiment 1 of the present invention includes plural piezoelectric elements which are placed on a substrate. Furthermore, multilayer piezoelectric elements are placed in a central portion of the substrate and single-layer piezoelectric elements are placed on an outer peripheral portion of the substrate.

With this, the piezoelectric speaker can reduce costs while reducing deterioration in sound characteristics by using single-layer piezoelectric elements on a portion having a low contribution ratio to vibration.

FIG. **1** is a plan view of a piezoelectric speaker **100** according to Embodiment 1 of the present invention.

FIG. **2** is a cross-sectional view of the piezoelectric speaker **100** in a face taken along line A0-A1 of FIG. **1**.

As shown in FIG. **1** and FIG. **2**, the piezoelectric speaker **100** includes a diaphragm **10**, a passivation film **14**, and a frame **15**. The diaphragm **10** includes a piezoelectric element **11** and a substrate **13**.

The piezoelectric element **11** is placed on the substrate **13** and is adhered to the substrate **13**. This piezoelectric element **11** is composed of four piezoelectric elements **11***a*, **11***b*, **11***c*, and **11***d*. The piezoelectric elements **11***c* and **11***d* are placed farther from the center of the substrate **13** than the piezoelectric elements **11***a* and **11***b*.

Moreover, the piezoelectric elements **11***a* and **11***b* are two-layered piezoelectric elements. The piezoelectric elements **11***c* and **11***d* are single-layer piezoelectric elements. Moreover, a thickness of each of the piezoelectric elements is equal in the present embodiment. Moreover, a thickness may be different between a two-layer piezoelectric element and a single-layer piezoelectric element.

FIG. **3**A is a cross-sectional view of the single-layer piezoelectric elements **11***c* and **11***d*. FIG. **3**B is a cross-sectional view of the multilayer piezoelectric elements **11***a* and **11***b*.

As shown in FIG. **3**A, each of the single-layer piezoelectric elements **11***c* and **11***d* includes a piezoelectric ceramics layer **21** and electrodes **22** and **23**. The electrodes **22** and **23** are placed on and under the piezoelectric ceramics layer **21** such that the electrodes **22** and **23** hold the piezoelectric ceramics layer **21** therebetween.

The multilayer piezoelectric elements **11***a* and **11***b* are elements in each of which a piezoelectric ceramics layer and an electrode are alternately layered. As shown in FIG. **3**B, the multilayer piezoelectric elements **11***a* and **11***b* each includes a piezoelectric ceramics layer **26** and electrodes **27** and **28**. The electrode **28** is an electrode layer which functions as an inside electrode. The piezoelectric ceramics layer **26** is composed of two layers, and the electrode **28** is sandwiched between the two layers. The electrode **27** is configured to vertically hold the whole of the piezoelectric ceramics layer **26** composed of two layers.

It is noted that a structure as shown in FIG. **3**C may be used as a structure of each of the single-layer piezoelectric elements **11***c* and **11***d*.

The frame **15** supports both edges of the diaphragm **10**. Moreover, in FIG. **1**, a gap is provided between the frame **15** and both edges in a longitudinal direction of the diaphragm **10**. It is noted that the frame **15** may support four sides of the diaphragm **10**.

The passivation film **14** is formed to cover the gap. It is noted that the passivation film **14** is provided to block sound radiated from a reverse side of the diaphragm **10**. This passivation film **14** is, for example, a film of styrene butadiene rubber (SBR). It is noted that the passivation film **14** may be provided only on an upper portion of a gap so as to fill the gap between the diaphragm **10** and the frame **15** and may be provided to cover the upper portion of the gap and the whole of the diaphragm **10**.

It is noted that a method of driving the diaphragm **10** by applying a driving voltage to a surface electrode (not illustrated) of the piezoelectric element **11** is similar to the conventional piezoelectric speaker.

Here, when the driving voltage is applied to the piezoelectric element **11**, a dome-shaped vibration mode occurs such that amplitude in the central portion of the diaphragm **10** is largest. Based on this vibration mode, a multilayer piezoelectric element having a large amount of distortion is used for the piezoelectric elements **11***a* and **11***b* having a high contribution ratio to amplitude, while a single-layer piezoelectric element having a small amount of distortion is used for the piezoelectric elements **11***c* and **11***d* having a low contribution ratio.

FIG. **4**A shows sound pressure frequency characteristics of the piezoelectric speaker **100** composed as mentioned above. In FIG. **4**A, a horizontal axis represents frequency and a vertical axis represents sound pressure. Sound pressure frequency characteristics **31**, as shown in a solid line, represent characteristics of the piezoelectric speaker **100** according to Embodiment 1 of the present invention, and sound pressure frequency characteristics **32**, as shown in a dotted line, represent characteristics in a case where a multilayer piezoelectric element is used for all piezoelectric elements. As shown in FIG. **4**A, sound pressure of the piezoelectric speaker **100** according to Embodiment 1 of the present invention is almost equal to sound pressure in the case where the multilayer piezoelectric element is used for all piezoelectric elements. Furthermore, a dip occurring around 500 Hz is eliminated by introducing a structure of a combination of a multilayer piezoelectric element with a single-layer piezoelectric element. In other words, the combination of the single-layer piezoelectric element with the multilayer piezoelectric element enables control of a resonance mode.

In this way, the combination of the single-layer piezoelectric element with the multilayer piezoelectric element enables characteristics to be similar to characteristics in a case of only the multilayer piezoelectric element, making it possible to further control the resonance mode. Moreover, element costs and power consumption can be reduced by addition of single-layer piezoelectric elements.

Moreover, the conventional piezoelectric speaker is composed of a sheet of the piezoelectric element **3**, while in the piezoelectric speaker **100** according to Embodiment 1 of the present invention, the piezoelectric element **11** is divided into four sheets, thus allowing stress at a time of distortion to be reduced. For example, in the case where a piezoelectric element is divided into four sheets, the stress at a time of amplitude is decreased by around 20% compared with the case where a sheet of piezoelectric element is used. Therefore, the piezoelectric speaker **100** can also gain an effect of increasing the reliability.

It is noted that in the above-mentioned description, a monomorph structure in which the piezoelectric element **11** is placed on only an upper side of the substrate **13** is described as an example, but there may be a bimorph structure in which the piezoelectric element is placed also on a reverse side. FIG. **4**B is a graph showing sound pressure frequency characteristics in the case where the bimorph structure is used. Sound pressure frequency characteristics **33**, as shown in a solid line, represent characteristics of the piezoelectric speaker according to Embodiment 1 of the present invention, and sound pressure frequency characteristics **34**, as shown in a dotted line, represent characteristics in the case where a multilayer piezoelectric element is used for all piezoelectric elements. As shown in FIG. **4**B, it is possible to gain an effect in a bimorph structure similar to the monomorph structure.

Moreover, in the above-mentioned description, the substrate **13** is a flat configuration, but there may be a configuration as shown in FIG. **5**. FIG. **5** is a cross-sectional view of a piezoelectric speaker **101** according to a variation of Embodiment 1 of the present invention. This piezoelectric speaker **101**, different from the piezoelectric speaker **100** shown in FIG. **2**, includes a substrate **43** and piezoelectric elements **41** and **42** instead of the diaphragm **10**. It is noted that in FIG. **5**, a bimorph structure is exemplified.

The piezoelectric element **41** is placed on a surface of the substrate **43**. This piezoelectric element **41** includes multilayer piezoelectric elements **41***a* and **41***b* and single-layer piezoelectric elements **41***c* and **41***d*.

The piezoelectric element **42** is placed on a reverse face of the substrate **43**. This piezoelectric element **42** includes multilayer piezoelectric elements **42***a* and **42***b* and single-layer piezoelectric elements **42***c* and **42***d*.

The substrate **43** includes a region on which the piezoelectric element **41** and the piezoelectric element **42** are placed and an edge portion **49** which is an outer peripheral portion of the substrate **43** and functions as a suspension. This edge portion **49** has a rolled shape as shown in FIG. **5**. Hence, use of the edge portion **49** having a rolled shape enables an increase in linearity of an amount of amplitude relative to an input voltage. With this, distortion can be realized.

It is noted that in FIG. **5**, the edge portion **49** is a portion of the substrate **43**, but may be composed of a separate component independent from the substrate **43**. In this case, the edge portion **49** is provided between the outer peripheral portion of the substrate **43** and the frame **15** and functions as a suspension for supporting the outer peripheral portion of the substrate **43** and the frame **15**. Moreover, this edge portion **49** may be connected all around between the substrate **43** and the frame **15**. Moreover, in this case, the passivation film **14** may not be used. As a result, it becomes easier to design the lowest resonance frequency f0. Moreover, a bimorph structure is exemplified in FIG. **5** but a monomorph structure may be used.

Moreover, in the above-mentioned description, a two-layer piezoelectric element and a single-layer piezoelectric element are combined, but a different number of layers, such as two layers and four layers, is acceptable according to necessary characteristics. It is noted as described above, deterioration in sound characteristics can be reduced and costs can be reduced by placing piezoelectric elements having a large number of layers on the central portion of the substrate **13** and placing piezoelectric elements having a small number of layers on the outer peripheral portion of the substrate **13**.

Moreover, a plurality of piezoelectric elements which have three or more different number of layers, such as a single layer, two layers, and four layers, may be combined. In this case, the number of layers may be increased when the piezoelectric elements are closer to the central portion of the substrate **13**.

Moreover, in the above description, four sheets of piezoelectric elements are used, but the number of elements may be increased so as to finely control a resonance mode. In other words, the present invention can be applied to a case where two or more sheets of piezoelectric elements are used.

Moreover, in the above description, a structure shown in FIG. **3**B is exemplified as a multilayer piezoelectric element, but a stack of single-layer piezoelectric elements may be used as a multilayer piezoelectric element.

Embodiment 2

A piezoelectric speaker according Embodiment 2 of the present invention includes piezoelectric elements placed on a substrate. Furthermore, single-layer piezoelectric elements are placed on a portion having large stress caused by bending vibration of the substrate and multilayer piezoelectric elements are placed on a portion having small stress caused by bending vibration of the substrate.

With this structure, the piezoelectric speaker can reduce amplitude of stress concentrated in a portion and can enhance reliability of the piezoelectric speaker.

FIG. **6** is a diagram showing a distribution of stress generated in the case where only a sheet of a piezoelectric element is used. In FIG. **6**, stress in a portion **51** is higher than stress in other portions.

In Embodiment 2 of the present invention, piezoelectric elements having a smaller number of layers than piezoelectric elements in the other portions are placed on the portion **51** having high stress. This enables stress generated in the portion **51** to be reduced, thus leading to an improvement of reliability. FIG. **7**A is a diagram showing locations of piezoelectric elements according to Embodiment 2 of the present invention. The piezoelectric elements **52** and **53** shown in FIG. **7**A have a smaller number of layers than the piezoelectric element **54**. For example, the piezoelectric elements **52** and **53** are single-layer piezoelectric elements and the piezoelectric element **54** is a multilayer piezoelectric element.

It is noted that in FIG. **7**A, the piezoelectric element **54** is composed of one sheet, but the piezoelectric element **54** may be composed of, for example, three sheets of piezoelectric elements for easy implementation. FIG. **7**B is a diagram showing the locations of piezoelectric elements in this case. The piezoelectric elements **52** and **53** shown in FIG. **7**B have a smaller number of layers than the piezoelectric elements **54***a*, **54***b*, and **54***c*. For example, the piezoelectric elements **52** and **53** are single-layer piezoelectric elements and the piezoelectric elements **54***a*, **54***b*, and **54***c* are multilayer piezoelectric elements.

Embodiment 3

In Embodiment 3 of the present invention, a method of electrically connecting the piezoelectric element **11** to the substrate will be described. Moreover, hereafter, a case where the piezoelectric element **11** is used as described in Embodiment 1 will be described as an example, but a similar structure can be applied to the piezoelectric elements described in Embodiment 2.

FIG. **8** is a perspective view of the piezoelectric element **11***a*. FIG. **9** is a top view of the substrate **13**.

It is noted that the whole structure of the piezoelectric speaker is similar to Embodiment 1 as shown, for example, in FIG. **1** and FIG. **2**.

A difference from Embodiment 1 is an electrode structure of the piezoelectric element **11** and that electrodes are formed by printing on the substrate **13**. Moreover, a material of the substrate **13**, for example, is polyethylene terephthalate (PET). Moreover, hereafter will be described an electrode structure of a piezoelectric element with reference to the piezoelectric element **11***a*, but structures of piezoelectric elements **11***b* to **11***d* are also similar to a structure of the piezoelectric element **11***a*.

As shown in FIG. **8**, in the piezoelectric element **11***a*, a positive electrode **62** and a negative electrode **63** are formed on both sides of the piezoelectric element **11***a* so as to apply an electric signal to the piezoelectric element **11***a*. Here, a pair of the electrodes **62** and **63** is equivalent to a pair of the electrodes **27** and **28** as shown in FIG. **3**B or a pair of the electrodes **22** and **23** shown in FIG. **3**C. Moreover, at least a portion of a surface of the electrodes **62** and **63** is exposed to the substrate **13** side face of the piezoelectric element **11***a*. In other words, the piezoelectric element **11***a* has the face in which both the electrodes **62** and **63** are exposed. In an example shown in FIG. **8**, there are four faces of the piezoelectric element **11***a* in which faces of both the electrodes **62** and **63** are exposed.

As a result, wiring of lead wire and the like becomes easier because an electrode can be connected from the same face on the piezoelectric element **11***a*.

Moreover, as shown in FIG. **9**, the substrate **13** has two electrodes **72** and **73** formed on a surface of the substrate **13**. These electrodes **72** and **73** are formed by printing on a face on which the piezoelectric element **11** is placed.

Moreover, the piezoelectric elements **11***a* to **11***d* are placed such that the face on which both the electrodes **62** and **63** are exposed is in contact with the face on which the electrodes **72** and **73** of the substrate **13** are formed. Moreover, each of the electrodes **62** and **63** of the piezoelectric element **11***a* shown in FIG. **8** is placed on the electrodes **72** and **73** on the substrate **13** and is connected to the electrodes **72** and **73**. This allows conduction of the electrodes **62** and **63** to the electrodes **72** and **73**. In other words, the electrode **72** is electrically connected to plural electrodes **62** which are included in the piezoelectric elements **11***a* to **11***d*. The electrode **73** is electrically connected to the plural electrodes **63** which are included in the piezoelectric elements **11***a* to **11***d*.

In other words, a combination of the piezoelectric elements **11***a* to **11***d* with the substrate **13** makes it possible to realize a leadless structure. As a result, also in the case of placing piezoelectric elements, assembly becomes easier by formation by printing, on a diaphragm, of an electrode corresponding to the pattern.

Moreover, while the conventional piezoelectric speaker uses metal as a substrate, PET resin is used for the substrate **13** in Embodiment 3 of the present invention. This makes the substrate **13** lighter, making it possible to obtain an effect of efficiency improvement. Moreover, resin has greater internal loss than metal. As a result, a quality factor (Q) of resonance of sound pressure characteristics can be reduced and therefore sound quality can be improved.

It is noted in the above-mentioned description, PET resin is used as a material of the substrate **13**, but other materials can be used as long as they are materials on which an electrode can be printed. For example, paper or foam can be used as a material of the substrate **13**. Use of paper or foam can realize lighter weight or higher internal loss, thus making it possible to realize higher efficiency and higher sound quality. More-

over, a strength of adhesion of electrodes can be increased, and therefore reliability also becomes higher.

Moreover, in the above-mentioned description, the two electrodes **62** and **63** of the piezoelectric element **11***a* are formed on both sides of the element, but a structure other than the structure described above is acceptable as long as it is a structure in which both electrodes are exposed together on at least one face.

The piezoelectric speaker according to the embodiments of the present invention has been described above, but the present invention is not limited to the embodiments described above.

For example, the present invention can be realized as audio equipment including the above-mentioned piezoelectric speaker. For example, the present invention can be realized as a television receiver **200**, as shown in FIG. **10**, including the above mentioned piezoelectric speaker and as a mobile phone device **201**, as shown in FIG. **11**, including the above mentioned piezoelectric speaker. Moreover, a piezoelectric speaker according to the present invention can be used in a speaker for a home theater or a speaker for an automobile.

Moreover, in each of the above described drawings, corner portions and sides of each component are linearly described, but the present invention also includes components including corner portions and sides that are round due to manufacturing considerations.

Moreover, at least a portion of configurations of piezoelectric speakers according to Embodiments 1 to 3 and variations thereof may be combined.

Moreover, all values used in the above descriptions are exemplified to describe the present invention in detail and the present invention is not limited to the exemplified values. Moreover, materials of each of the components exemplified above are exemplified to describe the present invention in detail and the present invention is not limited to the exemplified materials.

As long as there is no departure from the spirit and scope of the present invention, variations of the embodiments conceived by those skilled in the art also fall within the scope of the present invention.

The present invention can be applied to a piezoelectric speaker. Moreover, the present invention can also be applied to a flat panel television receiver, a mobile phone device, a speaker for a home theater, and a speaker for an automobile, all of which use a piezoelectric speaker.

REFERENCE SIGNS LIST

1 Piezoelectric sounding body
2 Frame
3 Piezoelectric ceramics plate
4 Metal plate
5*a* Inside electrode
5*b* Outside electrode
10 Diaphragm
11, **11***a*, **11***b*, **11***c*, **11***d*, **41**, **41***a*, **41***b*, **41***c*, **41***d*, **42**, **42***a*, **42***b*, **42***c*, **42***d*, **52**, **53**, **54**, **54***a*, **54***b*, **54***c* Piezoelectric element
13, **43** Substrate
14 Passivation film
15 Frame
21, **26** Piezoelectric ceramics layer
22, **23**, **27**, **28**, **62**, **63**, **72**, **73** Electrode
31, **32**, **33**, **34** Sound pressure frequency characteristics
49 Edge portion
51 Portion
100, **101** Piezoelectric speaker
200 Television receiver
201 Mobile phone device

The invention claimed is:

1. A piezoelectric speaker comprising:
a diaphragm including a substrate and a plurality of piezoelectric elements arranged on said substrate; and
a frame supporting said substrate at an outer peripheral portion of said substrate,
wherein each of said plurality of piezoelectric elements includes at least one piezoelectric body and at least one electrode, the at least one piezoelectric body and the at least one electrode being stacked,
wherein said plurality of piezoelectric elements includes a first piezoelectric element having a first number of layers, and second and third piezoelectric elements, each having a second number of layers, the first number of layers being larger than the second number of layers,
wherein said first piezoelectric element has a first contribution ratio to amplitude, and said second and third piezoelectric elements each have a second contribution ratio to amplitude, the first contribution ratio to amplitude being larger than the second contribution ratio to amplitude such that a distortion of said first piezoelectric element is larger than a distortion of each of said second and third piezoelectric elements,
wherein said first piezoelectric element is arranged on said substrate in a portion having a first stress, said second piezoelectric element is arranged on said substrate in a portion having a second stress, and said third piezoelectric element is arranged on said substrate in a portion having a third stress equal to the second stress, the first stress being smaller than the each of the second and third stresses,
wherein the first, second, and third stresses are caused by a bending vibration of said substrate, and
wherein said second piezoelectric element and said third piezoelectric element are symmetrically arranged with respect to a center of said substrate.

2. The piezoelectric speaker according to claim **1**,
wherein said second piezoelectric element and said third piezoelectric element are arranged farther from the center of said substrate than said first piezoelectric element.

3. The piezoelectric speaker according to claim **1**,
wherein each at least one electrode includes a first electrode and a second electrode through each of which an electrical signal is applied to said respective piezoelectric element, and
wherein each of said plurality of piezoelectric elements has a face on which both said first electrode and said second electrode of said respective piezoelectric element are exposed.

4. The piezoelectric speaker according to claim **3**,
wherein said substrate includes a third electrode and a fourth electrode which are formed by printing on a face on which said plurality of piezoelectric elements is arranged,
wherein said plurality of piezoelectric elements is arranged such that the face on which both said first electrode and said second electrode are exposed is in contact with the face of said substrate on which said third electrode and said fourth electrode are formed,
wherein said third electrode is connected to said first electrode included in each of said plurality of piezoelectric elements, and
wherein said fourth electrode is connected to said second electrode included in each of said plurality of piezoelectric elements.

5. The piezoelectric speaker according to claim **1**,
wherein said substrate is made of polyethylene terephthalate.

6. The piezoelectric speaker according to claim **1**,
wherein said substrate is made of paper.

7. The piezoelectric speaker according to claim 1, wherein said substrate is made of foam.

8. The piezoelectric speaker according to claim 1, further comprising

an edge portion which is provided between the outer peripheral portion of said substrate and said frame and which functions as a suspension.

9. The piezoelectric speaker according to claim 8, wherein said edge portion has a rolled shape.

10. A television receiver comprising a piezoelectric speaker according to claim 1.

11. A mobile phone device comprising a piezoelectric speaker according to claim 1.

12. The piezoelectric speaker according to claim 1, wherein said first piezoelectric element is arranged between said second piezoelectric element and said third piezoelectric element, and said first piezoelectric element is arranged over the center of said substrate.

13. The piezoelectric speaker according to claim 12, wherein said first piezoelectric element includes two piezoelectric elements, and said two piezoelectric elements of said first piezoelectric element are symmetrically arranged with respect to the center of said substrate.

14. The piezoelectric speaker according to claim 1, wherein each of said second piezoelectric element and said third piezoelectric element includes a three-layer structure comprising two electrode layers and one piezoelectric body layer, and wherein said first piezoelectric element includes a five-layer structure comprising three electrode layers and two piezoelectric body layers.

15. The piezoelectric speaker according to claim 1, wherein each of said plurality of piezoelectric elements comprises a surface having a rectangular shape, each of the surfaces being arranged on said substrate, and wherein said first piezoelectric element and said second piezoelectric element are arranged such that a longitudinal side of the rectangular surface of said first piezoelectric element is in contact with a longitudinal side of the rectangular surface of said second piezoelectric element.

16. The piezoelectric speaker according to claim 1, wherein, when a driving voltage is applied to said plurality of piezoelectric elements, a vibration mode occurs such that an amplitude in a central portion of said diaphragm is largest.

17. The piezoelectric speaker according to claim 16, wherein said vibration mode is dome-shaped.

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